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RESEARCH PAPER

Effects of industrial and residential sludge on seed germination and growth parameters of *Acacia auriculiformis* seedlings

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Abstract: A study was conducted to evaluate the effects of sludge (industrial and residential) on seed germination and growth performance of *Acacia auriculiformis* seedlings at the nursery of Institute of Forestry and Environmental Sciences, Chittagong University (IFESCU), Bangladesh. Before sowing of the seeds, different combinations of sludge were incorporated with the nutrient-deficient natural forest soils. Seed germination and growth parameters of the seedlings (shoot and root length, collar diameter, fresh and dry weight of shoot, and root and total dry biomass) were recorded after one, two and three months of seed sowing. Physio-chemical parameters (pH, organic carbon, nitrogen, phosphorus, and potassium) and heavy metals (chromium, nickel, manganese, cadmium and zinc) of each treatment were also analyzed before sowing of seeds and after harvesting of seedlings. Results show that the seed germination percentage and the seedling growth parameters varied significantly in the soil added with sludge in comparison to control. The highest germination percentage (90%) was observed in the treatment of soil with residential sludge of 2:1 compared to control. The highest growth and biomass of the seedlings as well as the maximum percentage of organic carbon and nutrients (N, P and K) were also recorded in the same combination. Soil added with industrial sludge had a higher concentration of heavy metal than that of residential sludge. The highest concentrations of heavy metals were found in soil added with industrial sludge of 1:1. It is recommended that soil added with residential sludge of 2:1 provide good condition for better seed germination and growth of *A. auriculiformis* seedlings in degraded forest soil.

Keywords: *Acacia auriculiformis*; germination; growth parameters; seedling growth; sludge

Introduction

Acacia auriculiformis (A. Cunn. Ex Benth.) is a fast-growing multipurpose tree species in the family Leguminosae. The species is a medium sized, heavily branched, evergreen tree with short, bent or forked bole, which tends to be fluted in the lower part (Das and Alam 2001). *A. auriculiformis*, as a vigorous nitrogen-fixing tree species, is able to establish and grow well in very poor soil, even in saline and seasonally water logged soils. In Bangladesh, *A. auriculiformis* is an exotic species, which is mostly planted as roadside avenue tree by the side of highways, railway tracks and parks, and also planted in tea gardens. Its wood is ideal for fire fuel and charcoal-making, and also suitable for furniture making as it has attractive figure and furnishes well. It is also a suitable species for planting as shelterbelt in the beach and sea front areas (Das and Alam 2001). Due to its multipurpose utility and wide range of ecological amplitudes (especially suitable to Bangladesh environment), *A. auriculiformis* is being planted in different parts of Bangladesh by the government and other public and private sectors in different plantation programs, e.g. agro-forestry, community forestry, village, and farm forestry programs, etc.

The treatment and disposal of industrial and residential sludges are an environmentally sensitive problem because sludge is good fertilizer but may contain heavy metals which could reduce productivity and cause environmental risks. The common disposal processes for sewage include land filling, land application and incineration. Among these, land filling is the first choice for sewage disposal. However, the future of sludge disposal through land filling is not very bright due to the fact that a large volume of soil is required to cover the waste in order to prevent the leaching of potentially toxic compounds including metals and phenols (Ahlberg et al. 2006). Sludge generated from various sectors have also been utilized in various agricultural uses due to the fact that significant amount of nitrogen, phosphorus and other organic matters are available in the industrial and domestic sludge (Warmen and Termeer 2005). Forested sites are increasingly receiving attention as potential sites for the disposal and biological recycling of both waste water and sludge from industrial treatment plants. The main advantage of using sewage sludge is the enrichment of the soil at a lower cost that is possible with inorganic fertilizers (Hossain and Miller 1994). It is

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obvious that, as with other organic materials, sewage sludge improves soil physical and chemical properties (Guidi and Hall 1984). Generally, sewage sludge is composed of organic compounds, macronutrients, a wide range of micronutrients, non essential trace metals, organic micro pollutants and micro organisms (Singh and Agrawal 2008). The most common types of sludge contain proportionately high amounts of total nitrogen (N). Total N content in domestic sludge may range from 1% to 15% by dry weight but is more commonly 3% to 6% of this being present as organic nitrogen. Phosphorous content is typically between 1% and 4% by dry weight while that of potassium ranges from 0.2% to 1% (McCalla et al. 1977). Unfortunately, it may also contain a range of potentially toxic metals, including Cu, Cd, Pb, Zn and Ni (Logan and Chaney 1983). Though land application of sludge has been practiced for decades, only a relatively small amount of sludge have been utilized in other industries, such as forestry, despite recommendations about its value as a fertilizer (Korentajer 1991). But heavy metals cause less concern when sludge is applied on forest land and nurseries, because forest is a non food chain. Metals at supra-optimal concentration in the growth media can function as stressors causing physiological constraints that decrease plant vigor and affect plant growth, development and yield (Fuentes 2004). This will cause negative impact on root weight, number of leaves, and shoots weight of plants (Huang et al. 1974). A primary concern for plants grown in sewage sludge is the accumulation of metals in the above ground tissues. This is also of paramount interest to phyto-remediation since the goal is to remove the largest mass of metal with each harvest. Metal removal by plants during phytoremediation is dependent not only on the tissue concentrations but also on the total biomass produced (Ebbs et al. 1997).

Mixing soil with sludge is of considerable interest and importance in sludge utilization (Riekerk and Zasoski 1979; Iqbal et al. 2007; Chandra et al. 2008). Fast growing tree species can be benefited from sludge application (Labrecque et al. 2006). Though much research has been done on the use of sewage sludge as crop fertilizers (Van den Berg 1993; Gardiner et al. 1995; Selivanovskaya et al. 1997; Selivanovskaya and Latypova 1999; Selivanovskaya and Latypova 2006), very few information is available in case of fast growing species especially in soil conditions of Bangladesh (Iqbal et al. 2007). In this study we evaluated the effects of different concentrations of residential and industrial sludge on seed germination and physiological parameters of *A. auriculiformis* seedlings. Moreover, physiochemical (pH, organic carbon, nitrogen, phosphorus, potassium) and heavy metal (chromium, manganese, nickel, zinc and cadmium) concentration of sludge amended soil were also analyzed.

Materials and methods

Site selection and seed collection

The study was conducted during February to June in 2007 at the nursery of Institute of Forestry and Environmental Sciences, Chittagong University (IFESCU), Chittagong, Bangladesh. The nursery site enjoys a tropical monsoon climate characterized by hot, humid summer and cool & dry winter. February (15°C) and May (31°C) are the coldest and warmest month, respectively. Relative humidity is the lowest (64%) in February and the highest (95%) in June. Degraded soils were collected from hilly sites and were sieved (< 3 mm) to obtain a uniform soil. The brown hilly soils are sandy loam to sandy clay loam, moderately to strongly acid, and poorly fertile with pH <5.5, organic matter <2%, CEC <10 me/100 g, and BSP < 40% (Osman et al. 2001). The seeds of *A. auriculiformis* were collected from the plantations of Chittagong University Campus, Bangladesh.

Sludge collection and experimental design

Sludges were collected from industrial and residential sites of Chittagong City, and then dried properly. The dried sludges were also sieved (<3 mm) to make them free from root splinters and other foreign materials. Then the soil and sludges were mixed thoroughly at different ratios. Polybags with 23 cm × 15 cm were used for the experiment. A Completely Randomized Design (CRD) was adopted for a total of seven treatments, including a control treatment and three replications for each treatment with 15 polybags for each replication (e.g. 45 polybags for each treatment and a total of 315 polybags for the whole experiment). The treatments used in the experiment were as follows:

Group	Treatment
T_0	Control (soil)
T_1	soil + industrial sludge(1:1)
T_2	soil + industrial sludge(2:1)
T_3	soil + industrial sludge(3:1)
T_4	soil + residential sludge(1:1)
T_5	soil + residential sludge(2:1)
T_6	soil + residential sludge(3:1)

Two seeds were sown in each polybag to observe the effect of sludge on field germination (e.g. a total of 90 seeds per treatment and 630 seeds for whole experiment for field germination test), and after completion of field germination only one seedling (best one) per polybag was maintained to observe the initial growth parameters of seedlings. Partial shade and covering was provided over the nursery to protect the seedlings from strong sunlight and rain. Proper care and maintenance were done from the starting time of sowing seed up to harvesting of seedlings. Watering, removal of weeds, grasses etc. were done regularly.

Assessment of physiological growth and nodule parameters

Field germination was recorded daily from the date of seed sown, continuing up to the last field germination of the seed. The seedlings were allowed to grow for three months from the time of seed sowing. After one month, five seedlings from each treatment were randomly harvested and carefully collected with entire roots intact. Then growth parameters of seedlings (shoot and root length, collar diameter, fresh and dry shoot and root weight) were assessed. Collar diameter was measured by using slide calipers. After taking the data of the above parameters back, the seedlings were oven-dried at 70ºC for 48 h until the constant weight was obtained. All the data were analyzed statistically by

using the computer software package SPSS with Duncan's Multiple Range Test (DMRT).

Physio-chemical and metal analysis of the sludge amended soil

Different physio-chemical parameters (pH, organic carbon, nitrogen, phosphorus, and potassium) of sludge amended soils were analysed in triplicate. Samples were collected before sowing of seeds and after harvesting of seedlings from each treatment in each month. In the laboratory, the collected samples were first sieved through a 10-mm mesh sieve to remove gravel, small stones and coarse roots, and then passed through a 2-mm mesh sieve. Each sieved sample was diluted with water using the ratio 1:2 to determine pH (using digital pH meter TOA, Japan). Total organic carbon was determined by wet oxidation followed by titration with ferrous ammonium sulfate or photometric determination of Cr^{3+} (Tiessen and Moir 1993). Total nitrogen, phosphorus, and potassium were also determined by following Micro-Kjeldahl digestion procedure. The total content of acid extractable heavy metals was determined in 1 g sample from each combination using wet oxidation with the concentrated HNO_3 and 3% H_2O_2. The metal concentrations were determined by Atomic Absorption Spectroscopy (Analyst-300, Perkin-Elmer).

Results

Seed germination and morphological growth parameters of the seedlings

The seed germination percentage and growth parameters of the seedlings significantly ($P<0.05$) varied in different treatments. The highest germination percentage (90%) was observed in treatment T_5 and the lowest (63%) in T_0 (Fig. 1). The effects of different sludge on morphological growth parameters of the seedlings like shoot length, root length, total length, and collar diameter of seedlings of different ages were shown in Table 1.

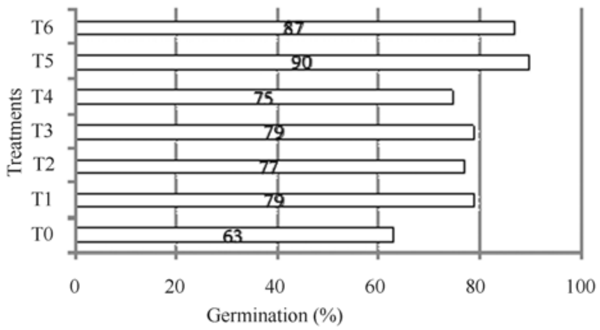

Fig. 1 Effect of sludge on germination of *A. auriculiformis* seeds

In 1-month-old seedlings, shoot height was the highest (44.0 cm) in treatment T_5, whereas the highest root length (16.9 cm) was recorded in T_4. The highest total length was found (57.6 cm) in T_5, and in addition, the highest collar diameter (4.3 mm) was also recorded in the same treatment. Though treatment T_0 and T_1 did not vary significantly, shoot height increased by 3.3 cm, and root length decreased by 0.2 cm from treatment T_0 to treatment T_1 (Table 1). In case of 2-month-old seedlings, the highest shoot growth (64.6 cm) was recorded in T_5 and the lowest (35.2 cm) occurred in T_0. Root length was the highest (24.5 cm) in T_4 but the total length was the highest in T_5. Moreover, the highest collar diameter (5.2 mm) was found in both T_2 and T_5. For 3-month-old seedlings, the highest shoot height (79.7 cm) was found in T_5, on the other hand, the highest root length (32.2 cm) and collar diameter (7.4 mm) were recorded in T_4, significantly different from that of control. However the highest total length (106.5 cm) was observed in T_5 and the lowest (65.7 cm) in control (Table 1).

Table 1. Effects of sludge on shoot height, root length, and collar diameter of *A. auriculiformis* seedlings of different ages

Age of seedlings	Treatment	Shoot height (cm)	Root length (cm)	Total length (cm)	Collar diameter (mm)
1- month	T_0	18.3 b*	7.4 b	25.7 d	2.8 b
	T_1	21.6 b	7.2 b	28.8 d	2.4 b
	T_2	29.1 ab	11.5 ab	40.6 bc	3.5 ab
	T_3	42.2 a	10.2 ab	52.4 ab	3.8 a
	T_4	39.4 a	16.9 a	56.3 a	4.0 a
	T_5	44.0 a	13.6 ab	57.6 a	4.3 a
	T_6	29.5 ab	6.8 b	36.3 c	2.5 b
2- month	T_0	35.2 b	11.5 b	46.7 d	3.9 ab
	T_1	37.2 b	13.2 b	50.4 d	3.6 b
	T_2	43.5 ab	15.2 ab	58.7 c	5.2 a
	T_3	63.8 a	16.3 ab	80.1 ab	4.8 a
	T_4	59.4 a	24.5 a	83.9 a	5.0 a
	T_5	64.6 a	19.4 ab	84.0 a	5.2 a
	T_6	41.3 ab	12.7 b	54.0 c	3.3 b
3- month	T_0	51.6 b	14.1 b	65.7 d	5.2 b
	T_1	58.4 ab	17.2 b	75.6 c	5.5 ab
	T_2	68.3 a	19.4 ab	87.7b c	7.1 a
	T_3	79.1 a	21.6 ab	100.7 ab	6.5 a
	T_4	74.2 a	32.2 a	106.4 a	7.4 a
	T_5	79.7 a	26.8 a	106.5 a	6.8 a
	T_6	53.2 ab	18.4 ab	71.6 c	4.5 b

* followed by the same letter (s) in the same column do not vary significantly at $P< 0.05$, according to Duncan's Multiple Range Test (DMRT).

Fresh and dry matter production

Fresh and dry matter production, e.g. shoot and root fresh weight, total fresh weight, shoot and root dry weight, and total dry weight were shown in Table 2. In 1-month-old seedlings, shoot fresh and dry weight were the highest (11.94 g and 7.86 g, respectively) in T_5, and were significantly ($p<0.05$) different from those of control. Root fresh weight was the maximum (0.98 g) in T_5 and the minimum (0.51 g) in T_6. Moreover, root dry weight was the highest (0.61 g) in T_5 and the lowest (0.33 g) in T_4 but total dry biomass was found to be the maximum in T_5 (8.47 g). When 2-month-old seedlings were considered, the highest shoot fresh (17.66 g) and dry weight (11.09 g) and the highest root fresh & dry weight (1.73 g and 1.21 g, respectively) as well as total dry weight (12.3 g) were found in treatment T_5, which significantly different from that of T_0. In case of 3-month-old seedlings, the highest shoot fresh and dry weight (24.85 g and 16.14 g, respectively) were both recorded in T_5 and the lowest (11.46 g

and 6.94 g, respectively) in T_0. Fresh root weight was the maximum in T_5 (2.56 g), whereas the highest dry weight was found in T_2 (1.74 g). Furthermore, the lowest root fresh and dry weight were recorded in T_6 but the total dry biomass was recorded to be the highest in T_5 (17.75 g).

Table 2. Effects of sludge on fresh and dry weights of shoot and root of *A auriculiformis* seedlings of different ages

Age of seedlings	Treatment	Fresh weight (g)			Dry weight (g)		
		Shoot	Root	Total	Shoot	Root	Total
1- month	T_0	4.09 d*	0.68 b	4.77 b	2.34 b	0.41 c	2.75 d
	T_1	6.14 c	0.72 b	6.86 bc	3.68 c	0.43 bc	4.11 c
	T_2	8.54 b	0.92 ab	9.46 a	5.87 b	0.54 b	6.41 a
	T_3	7.24 bc	0.88 ab	8.12 ab	4.97 bc	0.51 b	5.48 ab
	T_4	8.31 b	0.55 d	8.86 a	5.46 b	0.33 d	5.79 ab
	T_5	11.94 a	0.98 a	12.92 a	7.86 a	0.61 a	8.47 a
	T_6	10.08 a	0.51 c	10.59 a	6.73 ab	0.36 d	7.09 a
2- month	T_0	7.65 d	1.21 b	8.86 c	4.25 d	0.87 b	5.12 d
	T_1	9.68 c	1.48 ab	11.16 b	5.32 c	0.99 ab	6.31 c
	T_2	13.42 b	1.64 a	15.06 a	8.62 b	1.06 ab	9.68 ab
	T_3	12.49 b	1.61 a	14.1 a	7.70 bc	1.14 a	8.84 b
	T_4	13.24 b	1.18 d	14.42 a	8.71 b	0.74 c	9.45 ab
	T_5	17.66 a	1.73 a	19.39 a	11.09 a	1.21 a	12.3 a
	T_6	15.78 ab	1.12 c	16.9 a	10.65 a	0.68 d	11.33 a
3- month	T_0	11.46 c	1.94 c	13.4 bc	6.94 d	1.21 c	8.15 b
	T_1	16.79 bc	2.24 b	19.03 b	10.43 c	1.61 ab	12.04 ab
	T_2	18.24 b	2.51 a	20.75 ab	13.21 b	1.74 a	14.95 a
	T_3	16.66 bc	2.47 a	19.13 b	11.05 c	1.62 ab	12.67 ab
	T_4	18.36 b	2.39 ab	20.75 ab	12.30 bc	1.54 b	13.84 ab
	T_5	24.85 a	2.56 a	27.41 a	16.14 a	1.61 ab	17.75 a
	T_6	19.25 b	1.89 c	21.14 ab	13.33 b	1.05 d	14.38 a

* followed by the same letter(s) in the same column do not vary significantly at $p< 0.05$, according to Duncan's Multiple Range Test (DMRT).

Physio-chemical analysis of different sludge amended soil

Physio-chemical (pH, organic carbon, nitrogen, phosphorus and potassium) analysis of forest soils with different sludge before sowing of seeds and after harvesting of seedlings are presented in Tables 3 and 4, respectively. The value of pH differed significantly ($p<0.05$) among different treatments. The highest pH (6.20) was recorded in the treatment T_0, on the contrary, the lowest value (5.25) was shown in T_1 before sowing of seeds (Table 3). Though pH of the treatments T_0, T_3 and T_6 did not show significant difference, the pH of T_3 and T_6 were reduced by 0.22 and 0.24, respectively, from that of control. Furthermore, after harvesting of seedlings the pH was increased slightly in all the treatments but the highest pH (6.68) was detected in T_5 and the least value in the T_1 (Table 4) .

The experiment showed that the percentage of soil organic carbon was higher before sowing of seeds than after harvesting of seedlings. The highest amount of soil organic carbon (2.21%) was recorded in T_4 and the lowest amount (0.67%) in T_0 before sowing of seeds (Table 3). After harvesting of seedlings, the highest and lowest values were found in T_4 (1.83%) and T_0 (0.51%) (Table 4). From the experiment, it can be stated that during the growing period, a considerable portion of soil organic carbon was absorbed by the seedlings. Before sowing of seeds, the highest percentages of nitrogen, phosphorus and potassium (1.73%, 0.44%, and 0.37%, respectively) were found in T_4 and the lowest percentages of nitrogen and phosphorus were recored in T_0 and potassium in T_1 (Table 4). After harvesting of seedlings, the percentage of nitrogen was recorded maximum in T_4 and minimum in T_0. On the other hand, the highest percentages of phosphorus and potassium were found in T_4 (0.36% and 0.31%, respectively) and the lowest in T_0 and T_2, respectively.

Table 3. pH, organic carbon, nutrients (nitrogen, phosphorus and potassium) content of soils with and without sludge before sowing of seeds

Treatment	pH	Nutrients (%)			
		OC	N	P	K
T_0	6.20 a*	0.67 d	0.11 d	0.03 d	0.22 b
T_1	5.25 c	1.93 b	1.20 b	0.41 a	0.15 d
	(-0.95)	(+1.26)	(+1.09)	(+0.38)	(-0.07)
T_2	5.63 b	1.65bc	0.90bc	0.34bc	0.17 c
	(-0.57)	(+0.98)	(+0.79)	(+0.31)	(-0.05)
T_3	5.98 a	1.23 c	0.70 c	0.18 c	0.21 b
	(-0.22)	(+0.56)	(+0.59)	(+0.15)	(-0.01)
T_4	5.39bc	2.21 a	1.73 a	0.44 a	0.37 a
	(-0.81)	(+1.54)	(+1.62)	(+0.41)	(+0.15)
T_5	5.71 b	2.03ab	1.17 b	0.38 b	0.35 a
	(-0.49)	(+1.36)	(+1.06)	(+0.35)	(+0.13)
T_6	5.96 a	1.76bc	0.94bc	0.29bc	0.28ab
	(-0.24)	(+1.09)	(+0.83)	(+0.26)	(+0.06)

* followed by the same letter(s) in the same column do not vary significantly at $p<0.05$, according to Duncan's Multiple Range Test (DMRT); +/– value in the parentheses indicate the increased or decreased value from control treatment, OC = Organic carbon

Table 4. pH, organic carbon, nutrients (nitrogen, phosphorus and potassium) content of soils with and without sludge amended soil after harvesting of seedlings

Treatment	pH	Nutrients (%)			
		OC	N	P	K
T_0	6.63 a*	0.51 d	0.14 d	0.02 c	0.19 b
T_1	5.46 d	1.46 b	1.35ab	0.35 a	0.16 c
	(-1.17)	(+0.95)	(+1.21)	(+0.35)	(-0.03)
T_2	5.91 c	1.23bc	0.97 b	0.28ab	0.13 d
	(-0.72)	(+0.72)	(+0.83)	(+0.26)	(-0.06)
T_3	6.41 b	1.11 c	0.74 c	0.17 b	0.19 b
	(-0.22)	(+0.60)	(+0.60)	(+0.15)	(0.0)
T_4	5.93 c	1.83 a	1.81 a	0.36 a	0.31 a
	(-0.70)	(+1.32)	(+1.67)	(+0.34)	(+0.12)
T_5	6.68 a	1.65 b	1.29ab	0.27ab	0.26 ab
	(+0.05)	(+1.14)	(+1.15)	(+0.25)	(+0.07)
T_6	6.66 a	1.51 b	1.03 b	0.19 b	0.19 b
	(+0.03)	(+1.0)	(+0.89)	(+0.17)	(0.0)

* followed by the same letter(s) in the same column do not vary significantly at $p<0.05$, according to Duncan's Multiple Range Test (DMRT); +/– value in the parentheses indicate the increased or decreased value from control treatment. OC = Organic carbon

Heavy metal analysis

Heavy metals (chromium, manganese, nickel, zinc, and cadmium) of soils with different proportions of sludge before sowing of seeds and after harvesting of seedlings were shown in Table 5 and 6, respectively. Heavy metals concentration varied significantly ($p<0.05$) among the treatments. The highest concentra-

tions of chromium, manganese, nickel, zinc, and cadmium were shown in T_1 at the initial stage of the experiment. The chromium concentration was not significantly different between treatments T_0 and T_6 but in T_6 the concentration increased by 10 mg·L^{-1} from T_0. The lowest concentrations of manganese and nickel occurred in T_6 had the values of 81 mg·L^{-1} and 27 mg·L^{-1}, respectively (Table 5). After harvesting of seedlings, the highest concentrations of chromium, manganese, nickel, zinc, and cadmium were also recorded in T_1. In case of chromium, the lowest value was recorded in T_0 but this treatment did not significantly differ from T_6, and the concentration was 10 mg·L^{-1} lower than that value of T_6. However, the lowest concentrations of manganese and nickel were shown in T_6 (37 mg·L^{-1} and 26 mg·L^{-1}, respectively) (Table 6).

Table 5. Heavy metals (chromium, manganese, nickel, zinc and cadmium) content of soils with and without sludge before sowing of seeds

Treatment	Heavy metals (mg·L^{-1})				
	Cr	Mn	Ni	Zn	Cd
T_0	18 d*	290 bc	44 bc	38 d	0.02 d
T_1	325 a (+307)	422 a (+132)	91 a (+47)	783 a (+745)	19 a (+18.98)
T_2	261 ab (+243)	394 a (+104)	76 ab (+32)	421 ab (+383)	12 b (+11.98)
T_3	113 b (+95)	341 b (+51)	55 b (+11)	286 b (+248)	4 c (+3.98)
T_4	92 bc (+74)	124 c (-170)	38 c (-6)	154 bc (+116)	0.01 d (-0.01)
T_5	73 c (+55)	109 c (-181)	32 d (-12)	126 c (+88)	Trace
T_6	28 d (+10)	81 d (-209)	27 d (-17)	98 c (+60)	Trace

* followed by the same letter(s) in the same column do not vary significantly at $p<0.05$, according to Duncan's Multiple Range Test (DMRT); +/– value in the parentheses indicate the increased or decreased value from control treatment.

Table 6. Heavy metals (chromium, manganese, nickel, zinc and cadmium) content of soils with and without sludge after harvesting of seedlings

Treatment	Heavy metals (mg·L^{-1})				
	Cr	Mn	Ni	Zn	Cd
T_0	16 d*	284 b	38 bc	37 d	Trace
T_1	290 a (+274)	409 a (+125)	81 a (+43)	651 a (+614)	18.4 a
T_2	237 ab (+221)	360 ab (+76)	62 ab (+24)	387 b (+350)	10.3 b
T_3	97 b (+81)	311 b (+27)	49 b (+11)	261 bc (+224)	3.4 c
T_4	81 b (+65)	117 bc (-167)	34 bc (-4)	148 c (+111)	Trace
T_5	63 c (+47)	88 c (-194)	29 c (-9)	117 c (+80)	Trace
T_6	26 d (+10)	37 d (-247)	26 c (-12)	90 c (+53)	Trace

* followed by the same letter(s) in the same column do not vary significantly at $p<0.05$, according to Duncan's Multiple Range Test (DMRT); +/– value in the parentheses indicate the increased or decreased value from control treatment.

Discussion

The present study indicates that the germination percentage, growth parameters of *A. auriculiformis* seedlings, and the physio-chemical concentrations at different combinations of sludge treatments varied significantly compared to control. It was observed that the highest growth of *A. auriculiformis* seedlings was found in combination of soil and residential sludge (2:1). The present findings are in agreement with the conclusion of Jobra and Andres (2000) that sewage sludge could serve as a good organic fertilizer to maximize plant germination. Selivanovskaya and Latypova (2006) mentioned that sludge amendments enhanced the germination and decreased the mortality of the seedlings. The present study was also coincided with the studies from Labrecque et al. (2006) who reported that fast growing species can benefit from sludge amended soil. The results of the present study are also corresponded with that of Iqbal et al. (2007). They noticed that residential (soil + residential sludge = 1:1) sludge may be used for obtaining maximum and optimum seedling growth and nodule formation of *Leucaena leucocephala*. Moreover, our findings were partially agreed with that of Selivanovskaya and Latypova (2006). They found that the beneficial effects on the height of the shoots as well as on the length of the roots of pine seedlings were greater in plots with the highest rates of composted sludge, however, in the present study it was found that the root length was the highest in residential sludge amended soil (1:1). The present study also recorded that the concentrations of organic carbon, nitrogen, phosphorus and potassium were found to be the highest in T_4 (soil + residential sludge = 1:1) but the growth and biomass of seedlings were the maximum in T_5 (soil + residential sludge = 2:1). It is also interestingly observed that phosphorus and potassium were absorbed by the seedlings of *A. auriculiformis* whereas nitrogen content was found at an increasing rate in sludge amended soil at all the treatments. It may be due to the ability of *A. auriculiformis* to fix atmospheric nitrogen to the soil by the formation of nodules on roots. Riha et al. (1983) reported that the nitrogen content in the sludge was usually released more slowly than commercial fertilizers. This slower release is probably more appropriate for tree growth. Becker et al. (1991) revealed that nitrogen accumulation was higher with the application of P and K. The present study partially supports the results of Abdel-Wahab (1985) who explained that roots were relatively richer in nitrogen (dry weight basis) in K-rich conditions. He also mentioned that a significant amount of the nitrogen fixed was exuded at a low level of K supply. Sludge typically contains large amounts of plants available N and P, smaller amounts of all the secondary and micro nutrients and in addition, supplies organic matter (Bates et al. 1979).

It was observed from the present study that heavy metals (Cr, Mn, Ni, Zn, and Cd) concentration varied significantly ($p<0.05$) among the treatments. The highest concentrations of heavy metals were found in T_1 (soil: industrial sludge = 1:1) but maximum growth and biomass of seedlings were recorded in T_5. The concentration of heavy metals was also reduced in different combi-

nations of sludge amended soil from their original value. It can also be said that plants can be able to reduce heavy metals from the sludge amended soil. This study also reveals that the concentation of heavy metals in industrial sludge is higher than that in residential sludge. Depending upon source, sludge contains varying concentrations of Al, B, Cd, Cu, Ni, Pb, and Zn. Cd has been identified as the potentially most hazardous heavy metal elements when sludge is applied to land (Fresquez et al. 1991). The simultaneous phyto-separation of toxic and beneficial elements from sewage sludge is possible by using specific plants of co-cropping without the input of any chemicals (Wu et al. 2007). Moreover, the influence of sludge amended soil on plant growth is positive which is comparable to findings recorded by others (Jobra and Andres 2000; Selivanovskaya and Latypova 2006; Labrecque et al. 2006; Iqbal et al. 2007).

Conclusion

Industrial and residential sludge provide a potential source of nutrients to the seedlings of forest trees, and such use can satisfy the needs for environmentally safe disposal. Application of sludge is appropriate in non-food chain crops like in nursery soil to raise quality seedlings and also in forest lands other than agricultural use. It is necessary to find out the accurate rates of sludge application in order to avoid over or under fertilization and to reduce the risk of extensive heavy metal additions. From the present findings, soil and residential sludge (2:1) is recommended to be applied to nursery soil, based on the evidence that *A. auriculiformis* seedlings show better growth compared to valley soil.

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